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White Paper

Intel Labs

Silicon Photonics
New Opportunities for Silicon

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Intel recently demonstrated a tunable-optical filter that was fabricated in a standard CMOS silicon fab. This is one example of how Intel is expanding Moore's Law to encompass not only the relentless miniaturization of transistors, but other factors that make silicon more powerful than ever—including the expanding ability to create other functions such as optical switches, tunable filters, and optical modulators out of silicon.

Opportunities: *Photonics and the Internet Explosion*

Today, both home and business computers are limited less by processor performance than by the rate at which data can be transmitted between the processor and the outside world. Major corporations, financial institutions, and virtually all businesses and consumers demand instant and reliable transmissions, whether their data is traveling across the street or around the world. Corporate LAN and Internet traffic already exceeds telephony traffic, and Internet traffic has been doubling every year.

Copper-based networking can no longer keep up, so the telecommunications industry has turned to fiber optics to fulfill the growth demands of Internet traffic. But optical networks are arcane and expensive. Because of their high costs, their use has been limited primarily to long-haul and backbone networks.

Dense Wavelength Division Multiplexing (DWDM) is a technology that boosts capacity on fiber-optic cables by sending multiple wavelengths of light on a single fiber. Since the first DWDM systems were deployed in the mid-1990s, the number of channels supported on a fiber has increased from less than 16 to more than 40. Multiple channels are now transmitted over longer distances operating at 10 gigabits per second (Gbps). The evolution toward faster data rates will drive the fiber-optic industry to move next to 40 Gbps and to even higher data rates in the future. With the combination of higher data rates and DWDM capabilities, telecommunication companies will be able to transmit a trillion bits of data per second on a single fiber—a rate that would exceed the total traffic on the entire Internet today.

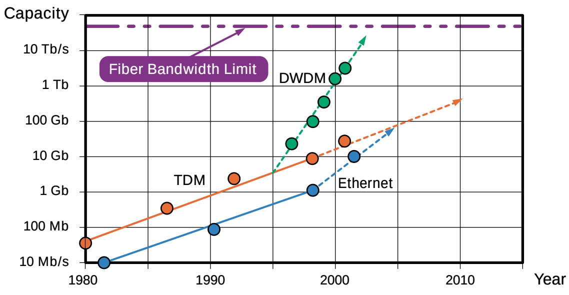

Figure 1. Capacity growth on a single fiber.

Technical Challenges

Optoelectronics—the union of optics and electronics—involves converting electronic signals to light pulses and vice versa, for transmission and processing of information over networks.

A typical optical network today contains numerous components: a laser source or transmitter, a multiplexer/demultiplexer (mux/demux) to combine all the optical wavelengths, amplifiers to amplify signals, components to demultiplex the signals, and receivers to convert optical signal back to electrical. These components are big, bulky, often hand-assembled and expensive.

Over the past decade, optical communications technologies have migrated out of the long-haul backbones and steadily moved into the network edge, invading Metro-Area Network (MAN) and campus-level LAN environments. While large amounts of aggregated and groomed traffic will continue to be transported over long-haul links, a key inflection point will come with the ability to economically connect central offices and diverse network access points together. One of the most important consequences of this migration has been the need to develop more efficient and lower-cost optical solutions. The future for optical networking rests upon developing the ability to bring this optical signal from the MAN, LAN, and data center to the curb, the home, and someday directly to the PC.

Intel Research Focus

Intel expects to allocate over $4 billion in research and development in 2002 with its research and advanced development focusing resources in five key areas: silicon technology and manufacturing, microarchitecture and circuits, computing hardware, computing software and networking and communications. Photonics will play a role in all of these areas.

Intel has many active internal research efforts focused on photonics. The Intel Labs research community is continuously creating new materials, new structures, and new architectures to enable the evolution of photonics from discrete devices to integrated photonic systems. These efforts range across a wide spectrum of communication areas progressing from 10Gb transmitters and modules to high-speed ICs, to longer range research activities looking at chip-to-chip interconnects. Intel also teams with academic researchers and supports innovative university research projects.

One research activity being conducted by Intel Labs is in silicon photonics. Silicon photonics aims to determine how to use silicon and standard silicon processing techniques to build optical devices. The concept is based on developing optical building blocks that give active functionality rather than simple, passive optical wave-guiding. These tiny silicon building blocks can in the future be selectively placed into optical modules, reducing cost and size. The process development activities for this research are being carried out in Intel's facility in Israel (Fab 8), where Intel's MEMS (Micro-ElectroMechanical Systems) activities are also being developed.

The core of this research is based on a novel approach that allows dynamic electronic control of optical signals with no moving parts. Some of the devices that could result from this research include optical filters, fast switches (~10ns), and very fast optical modulators (>GHz). To date, this effort has produced many functional optical devices—all in silicon.

One such device is a tunable optical filter that Intel showcased at the Intel Developer Forum Conference in February 2002. The filter is on the order of few microns wide by a couple of millimeters in length and can filter wavelengths in the DWDM spectrum. The small form factor outlines the potential value of developing these photonic devices in silicon. However, there is a fundamental limit that stems from the inherent nature of photons, in shrinking these devices to dimensions smaller than a few microns. Producing optical devices in silicon does afford the opportunity to integrate various functions together in a much smaller form factor than exists today. In addition, the industry can use silicon combined with standard IC manufacturing and assembly technologies to produce novel low-cost packaging and assembly technologies. This is the real opportunity and value of silicon photonics, irrespective of specific device or applications.

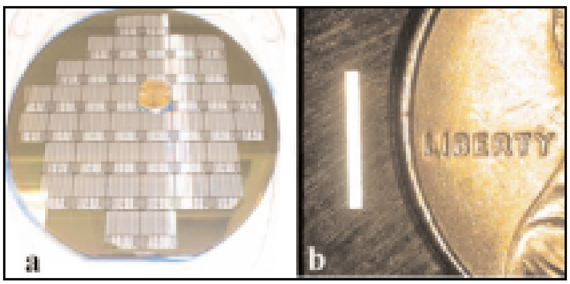

Figure 2. (a) Silicon photonics wafer processed at Fab 8 in Israel.
(b) Three optical filters fit into this tiny piece of silicon.

Looking Ahead

The Internet explosion has spurred the growth of the photonics industry. Future photonics technology evolution promises high-speed, high-capacity fiber-optic Internet communications for use in next-generation applications in education, medicine, entertainment, and commerce. Intel is actively developing solutions that enable high-volume manufacturing, integration and more cost-effective packaging capabilities. The goal of bringing optical networking down to the curb and ultimately to the PC can only be met if high-performance, low-cost, low-power optical components are available. Intel Labs will continue to research approaches to span smaller distances with photonic interconnects between components and ultimately between circuits.

In some ways, the photonics industry is where the semiconductor industry was in 1970. However, 30 years ago, we didn't have the Internet or the high-volume fabrication plants that we have today. We also did not have the expertise 30 years ago to increase microprocessor capacity, garnishing another 25 MHz that we now measure in months instead of years. With photonics, circuit densities can continue to double every 18 months for decades upon decades to come, another example of how Intel Silicon expertise is being applied in how arenas to expand the impact of Moore's Law.

Expanding Moore's Law, Expanding the Power of Silicon

Moore's Law started as a simple observation. It has since become a beacon for the electronics industry, guiding the efforts of chip developers and showing the rate of progress we must maintain in order to remain competitive. Now, Intel is driving an expansion of Moore's Law to accommodate not just increased transitor couunt but also the rising complexity of silicon-based devices and the convergence of additional devices and technologies integrated onto the chip. By extending the reach of silicon devices and applying the principles of Moore's Law to new classes of functionality, Intel's research is bringing about a new computing and communications geography, making these technologies more affordable and widespread and opening the door to broad new areas of innovation. And is doing so, Intel is ensuring that Moore's Law remains in effect for decades to come, through a combination of transistor count, complexity, and convergence.

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About the Authors

Mario Paniccia is principal engineer and director of Photonics Research and Development for Intel. Dr. Paniccia has been involved in many different areas of optical research thoughout his career. He has participated in developing optical testing technology, working on optical interconnects, optical clocking, and optical communications. Mario leads a research team focused on developing silicon-based photonic devices using standard silicon processing techniques. Mario received his B.S. in physics from State University of New York at Binghamton in 1988 and a Ph.D. in physics in 1994 from Purdue University. Mario has published numerous papers, been awarded 15 issued patents and has an additional 25 patents pending.

Shekhar Y. Borkar is an Intel Fellow in the Enterprise Platforms Group and director of Circuit Research at Intel Labs. Dr. Borkar is responsible for directing research in low-power circuits and high-speed signaling for Intel's future microprocessors. He received an M.S. in electrical engineering from the University of Notre Dame in 1981, and M.S. and B.S. degrees in physics from the University of Bombay in 1979.

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